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ABSTRACT

Traditional community antenna TV (CATV) systems are designed for program distribution and, as a result, adopt the "tree" network structure. However, this system is not satisfactory in urban environments. There are three solutions to this "lost channel" problem: (1) dual-cable systems; (2) channel converters; and (3) switched CATV systems. In addition, the new Federal Communication Commission (FCC) CATV report and order states that two-way capability will be required in all systems in the top 100 markets by 1977. This service will be capable of remote TV origination, but will not have the channel capacity for private, two-way video conversations in the telephone sense. However, data transmission and services (polling, meter reading, conference call hookups, frame-grabbing, etc.) will be extensive. Two-way services will emerge over the next few years, but their rate of growth is extremely hard to predict at this time. The cable system in a university can be organized like those to subscribers homes; Case-Western-Reserve and Massachusetts Institute of Technology are already experimenting in this area. (WCM)

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Cable Television Hardware: The State of the Art

by John E. Ward

TRADITIONAL CABLE TECHNOLOGY

Traditional Community Antenna TV (CATV) systems, of which some 3,000 are now in operation, use well-sited master antennas to pick broadcast TV signals from broadcast TV stations at the highest possible quality level and deliver them via cable to the antenna terminals of subscriber TV sets in place of the signals which might be picked up with individual antennas.[1] Since the usable range of cable frequencies extends only slightly above the upper-band edge of VHF Channel 13 of 216 MHz (currently to 300 MHz in the best systems), carriage of UHF-TV frequencies (470-890 MHz) is not feasible, and UHF stations, if carried, must be translated to VHF channels that can be tuned by the subscriber TV sets (or cable converters, as will be described). If the standard TV set is the only subscriber device, a traditional CATV system is thus limited to a maximum of 12 channels (VHF Channels 2-13).

Since traditional CATV systems were only concerned with program distribution, they early adopted the "tree" network structure, analogous to the water and electric power distribution networks. As shown in Fig. 1, off-the-air and local origination signals (if any) are processed at the "head end" (frequency translations as necessary, amplification, and so on) and

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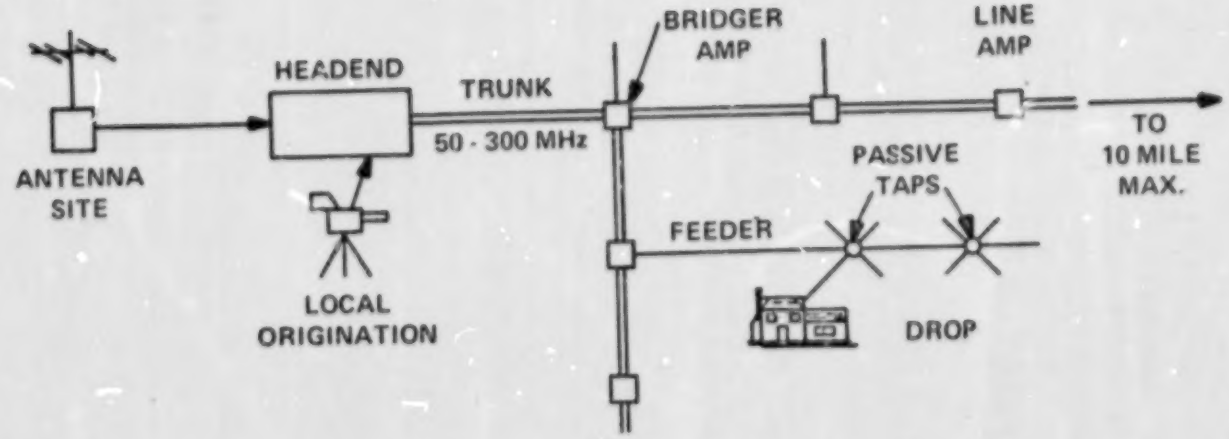


Fig. 1 Tree-Network CATV System

applied to a trunk cable, which is typically an aluminum-sheathed coaxial cable 0.5-0.75 inch in diameter. Trunk-line amplifiers are inserted about every 17 db of signal attenuation, or roughly every 1,500 feet, and because of loss of signal-to-noise ratio of each amplification, amplifier cascades are limited to about 50-60 amplifers total, or 10-15 miles of trunk.

Some of the trunk amplifiers are "feeder" or "bridger" amplifiers which also provide isolated outputs for 2-4 sub-trunk or feeder cables, typically 0.412" in diameter. Subscriber drop cables (typically 0.250") are connected only to feeder cables, using passive splitters. The engineering and maintenance of an overall distribution cable system, which must maintain proper signal levels and quality for all channels at each subscriber terminal, is a difficult task. Particular problems are the two-to-one increase in cable attenuation from Channel 2 to Channel 13, temperature effects on cables and amplifiers, distortions and nonlinearities, reflections, and proper shielding and grounding.

INCREASED CHANNEL CAPACITY FOR DISTRIBUTION

As has been described above, a traditional tree-structured, single-cable system should have a capacity of 12 program distribution channels. Unfortunately, not all 12 channels are always usable in urban environments because of "on-channel pickup", an interference created in a TV-set tuner between strong VHF stations and the same channels on the cable as a result of leakage pickup in the TV set of the off-the-air signals. The interference is manifest by ghosting due to a time difference between the direct-pickup and cable signals, and when this occurs, it is necessary to abandon use of the local station channels on the cable and translate their signals to "quiet" VHF channels in the same manner that UHF stations are carried on the cable. The actual total of the program channels that can be carried on a traditional single-cable CATV system may be as few as six or seven in the major markets with many VHF stations.

It should be noted that the on-channel pickup problem is not a fault of the cable system, but is a result of the fact that TV sets are designed for broadcast use, for which shielded front ends have never been necessary. The cost of adding proper shielding in new TV set designs is nominal, and a number of set makers now offer shielded sets with special 75-ohm input jacks for cable use, in addition to the standard 300-ohm antenna terminals. However, it is estimated that it would take at least 10 years to turn over a substantial fraction of present sets, even if only shielded sets were produced from now on, and shielded sets thus cannot be relied on as an immediate solution to the on-channel interference problems.

Dual-Cable Systems: The first solution to this "lost channel" problem in CATV was simply to install two parallel cable systems (including subscriber drops), each carrying different programs on the usable channels,

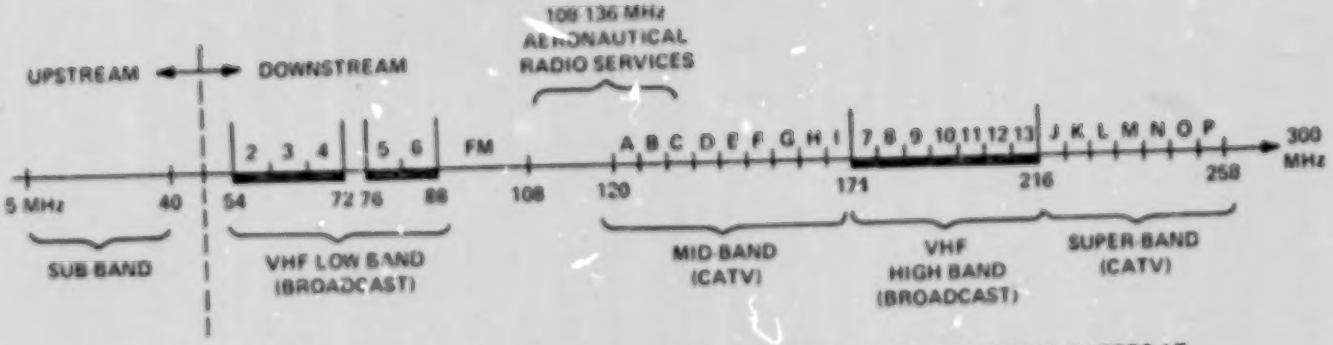
and provide each subscriber with an A/B switch to select between cables. A number of current systems are of this type and many new ones are planned. A typical dual-cable system is the one in Malden, Massachusetts, which has 18 usable program channels (three channels are lost on both cables due to the strong signals of Boston stations on Channels 4, 5 and 7). Installation of two cables at the same time costs about 50 percent more than a single cable.

Channel Converters: A second approach to the lost-channel problem is the set-top converter, an additional piece of equipment provided to each subscriber, which fits in the cable drop ahead of the TV set and performs all or part of the tuning function, analogous to the first UHF converters in the early 1950s. The first models (1966) were VHF/VHF converters, which handled only the 12 VHF broadcast channels and whose main purpose was to permit channel tuning to be performed in a shielded environment rather than in the TV set. The converter output is at a fixed channel frequency chosen for minimal interference (no local VHF station), and the TV-set tuner is left tuned to this channel. VHF/VHF converters eliminate on-channel carriage problems and yield 12 usable channels under all conditions.

More recently, new "augmented-channel" converters have appeared which provide increased cable channel capacity by tuning additional "cable" channels placed in the large frequency gap between Channels 6 and 7 (the "mid-band" channels) and/or above Channel 13 (the "super-band" channels). Figure 2 shows the total cable spectrum from 5-300 MHz, and indicates both the fixed FCC broadcast channel assignments for VHF-TV, and the ad hoc usage of other frequencies that is generally (but not universally) accepted within the cable industry. Note that use of *any* frequencies other than VHF Channels 2-13 requires some sort of special added tuning device for each subscriber, since TV sets tune only Channels 2-13.

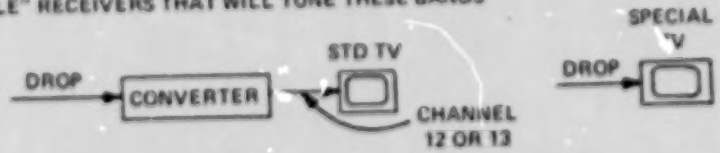
Augmented-channel converters are of two types –tunerless "block" converters and tuner-type converters. The block converters usually translate a group of seven mid-band or super-band cable channels to "high-band VHF" (Channels 7-13) for tuning by the TV set, although one type converts cable channels to an unused portion of the UHF band for tuning by the UHF converter of the TV receiver. Block converters have a switch which in one position permits normal channel reception and in the other substitutes the translated channels. Note that on-channel interference problems still exist with block converters which translate to high-VHF band because the TV set does the actual channel tuning.

The augmented-channel converters of tuner-type are similar to the shielded VHF-VHF converters previously described, except that the tuner is designed to handle more than 12 channels. Typical models presently in use are designed to tune nine mid-band channels (120-174 MHz) and four



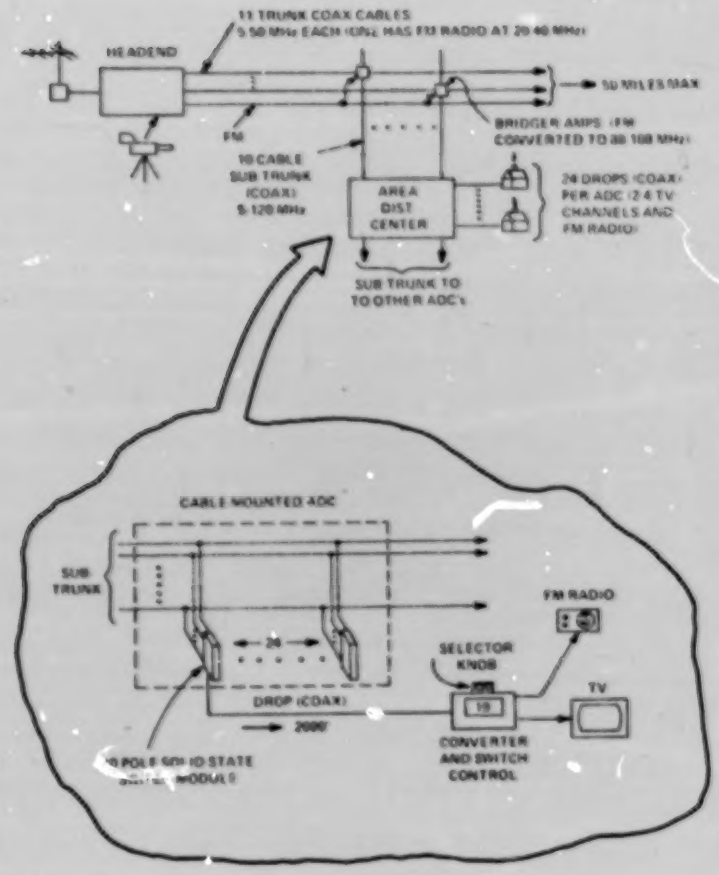
1. USE OF SUB-BAND FOR 3-4 UPSTREAM TV CHANNELS PLUS DATA REQUIRES ADDING FILTERS AT EACH CABLE AMPLIFIER, AND AN UPSTREAM 5-40 MHz AMPLIFIER ABOUT EVERY OTHER DOWNSTREAM AMP.

2. USE OF MID-BAND AND SUPER-BAND REQUIRES EITHER A CONVERTER PER SUBSCRIBER, OR SPECIAL "CABLE" RECEIVERS THAT WILL TUNE THESE BANDS



3. NO BANDS OTHER THAN 2-13 STANDARDIZED AT PRESENT. FAA FEARS POSSIBLE INTERFERENCE FROM DEFECTIVE CATV SYSTEMS AND MAY RECOMMEND NO USE OF MID-BAND

Fig. 2 Frequency Spectrum



DISCADE IS A COMBINATION FREQUENCY AND SPACE SWITCHING SCHEME. THE SELECTOR GOES THROUGH THE TWO (OR FOUR) CHANNELS ON ONE SUB-TRUNK CABLE, AND THEN SIGNALS THE SWITCH MODULE TO CHANGE THE DROP TO THE NEXT CABLE, ETC. CAPACITY IS 20 (OR 40) TV CHANNELS.

Fig. 4 Ameco "DISCADE™" System

super-band channels (216-240 MHz), in addition to the 12 VHF channels, or 25 total. Here again, technical problems have arisen – trouble is being experienced with inter-channel interference effects (harmonics, intermodulation, images, and so on) between these new channels and the standard VHF channels and it appears that not all these 25 channels can always be used, at least with the present ad hoc frequency assignments for the new cable channels.[2] New converter designs are now appearing that are designed to counteract cable interference problems. These new converters tune 30-36 channels and cost about $40 each in quantity. Probably no more than 300,000 converters of all types are yet in use.

Note that the converters just described can also be used on dual-cable systems, immediately providing up to 36 channels per cable, or up to 72 channels total. A number of "high-channel-count" systems now being installed or planned are taking this approach for several reasons:

(a) a dual-cable system gives a capacity of 12-18 channels even without converters and the systems can start up this way
(b) capacities of up to 72 channels can later be obtained by adding presently available converters.
(c) a dual cable system affords maximum flexibility for possible advances in two-way cable uses (to be described later)

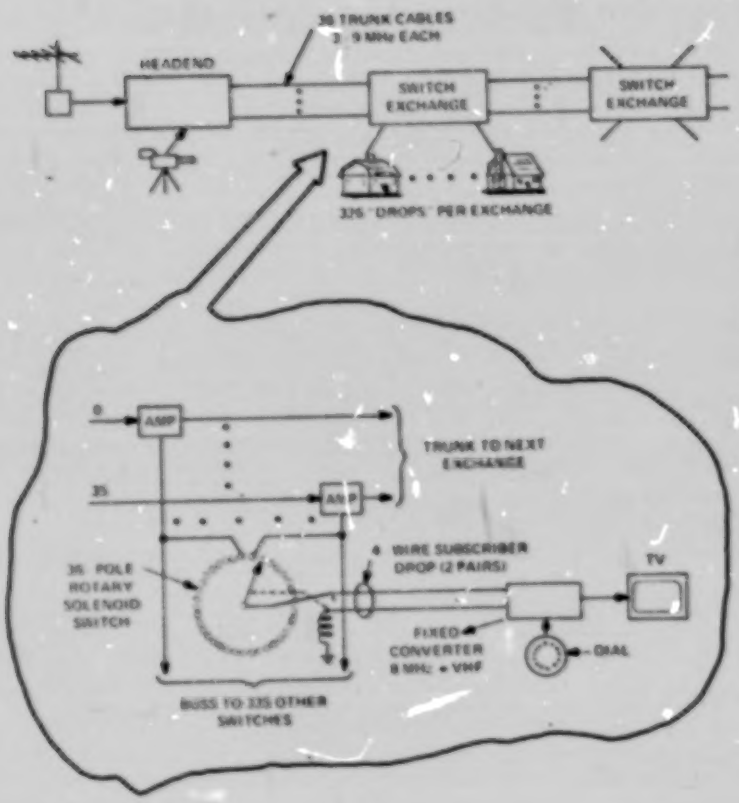
As a final comment on converter systems, it should be noted that use of two tuners in cascade (one in the converter, one in the TV set) is hardly the ideal situation from either the cost or the performance viewpoints. It would obviously be much more desirable to have cable TV sets which directly tuned all cable channels, contained the necessary shielding, and were designed to avoid a host of other cable interference problems not mentioned above – adjacent channel pickup, image reception, beats due to oscillator radiation from adjacent sets, IF beats, intermodulation, and so on. One such set announced by Magnavox at the 1971 National Cable Television Association Conference tunes 101 channels (including UHF). However, this raises the interesting question as to who should own such special receivers – the cable system or the subscriber? Also, cable channel frequencies other than the 12 VHF broadcast frequencies are still unstandardized and subject to a good deal of discussion at the present time because of (to list a few factors); continuing technical problems, competing two-way concepts (to be discussed later), and the present opinion of the FAA that cable systems should be prohibited from using any aeronautical navigation or communication frequencies (108-174 MHz), because of the potential danger of interference with aircraft operations in case of a cable break. Large-scale production of special cable receivers (or of cable converters) will depend on solutions to these questions. The FCC Cable Television Advisory Committee (CTAC) is studying the cable spectrum and is due to make its recommendations by the end of 1974. An EIA committee (CTSC) is expected to issue

recommendations for cable receivers in early 1974.

Switched CATV Systems: The third solution to the lost-channel augmentation problems has recently been put forward by at least two companies -- Rediffusion, Ltd. (a British company) and Ameco, Inc. (Phoenix, Arizona). Their idea is to abandon the concept of a broadband, frequency division multiplex "pipe" into every home, with each subscriber having his own demultiplexing equipment (a tuner), and go to a switched network in which the subscriber drop carries only 1-4 channels, and the programs on these channels are switched remotely. By utilizing only "sub-band" frequencies below 50 MHz (i.e., below Channel 2), a switched system avoids all the interference problems of the systems described above. In addition, a switched system offers almost unlimited channel capacity, determined only by the number of channels available at the switching center and the size of the switch.

The basic implementations of the Rediffusion "Dial-a-Program" and Ameco "DISCADE" systems are shown in Figs. 3 and 4. Note that a distribution trunk is still required in both cases to feed the exchanges, and that the switched network really only replaces the broadband feeders and subscriber drops, with all thier associated bridger amplifiers, splitters, and so on. Note also that this residual trunk is implemented differently than in traditional systems--a coaxial cable per program channel in the Rediffusion system, and a cable per two or four channels in the Ameco system. However, these can be small-diameter cables because of the low attenuation in the 5-50 MHz band, and trunk costs are only slightly higher than for a single, large-diameter, frequency-multiplex trunk. The hub networks between the switches and the subscribers are also small-diameter cables, and in the case of Rediffusion, not a coaxial structure at all but a twisted-wire structure not unlike telephone cable. The Rediffusion cable is called *Qwist*™ and consists of four wires twisted together -- two 25-gauge and two 26-gauge. The 25-gauge pair is usable from 0-15 MHz, and the 26-gauge pair (originally planned for control signals) from 0-6 MHz. For feeders from the exchanges, a cable with six Qwists in one sheath (3/8" diameter) is used. Individual Qwists are used for the final subscriber connections. The present limit on maximum subscriber distance from an exchange is 2,000-2,500 feet unless individual line amplifiers are fitted, thus, the exchanges are small and widely dispersed compared to telephone practice.

These present switched-system implementations offer a sound technical solution to the problems of supplying 36-40 (or more) high-quality program channels, and of channel security (for pay-TV, for example). They also offer the possibility of using simplified TV sets (no tuner required), and Rediffusion states that a per-set saving of up to $30.00 is possible, which will about pay for the subscriber program selector device. The disadvantages of the switched systems are the greater



DIAL A PROGRAM IS A SPACE SWITCHING SYSTEM. THE PROGRAM EXCHANGES ARE PART OF THE TRUNK SYSTEM AND EACH REQUIRES ABOUT 100 SQUARE FEET OF PROPERTY AND A SMALL BUILDING OR ENCLOSURE. THE PRESENT 325 SUBSCRIBER 36 CHANNEL DESIGN WOULD BE INSTALLED ABOUT 10 PER SQUARE MILE IN TYPICAL URBAN AREAS. THE SUBSCRIBER DROPS (UP TO 2000') ARE A SPECIAL TWISTED WIRE CABLE.

Fig. 3 Rediffusion "DIAL A PROGRAM" System

complexity of the subscriber-drop system (and its greater bulk, which is especially important in underground installations), the added cost of the switchgear, and the fact that homes with more than one TV set to be used independently must be double or triple subscribers (Rediffusion estimates that 40 percent of homes will need more than one house drop and exchange switch). In the case of Rediffusion, a further problem is that ground sites are needed for the exchanges (the Ameco system is entirely cable-mounted). Cost analyses[3] indicate that the Ameco system presently costs perhaps 15 percent more per subscriber than frequency-multiplex methods of supplying 40 channels, and Rediffusion about 90 percent more.

From the point of view of this conference, it is of interest to note that a 12-channel Rediffusion Dial-a-Program system (somewhat modified from the preceding description) has been in operation at Case-Western-Reserve University, Cleveland, Ohio, for the past 18 months. This system, used in the medical school, currently has 60 outlets and transmits color TV in the French SECAM system (programs are prepared in NTSC standards and then converted to SECAM before storage on tape cassettes for system use). A viewer may not only select a channel, but remotely control the video tape recorder; rewind, fast-forward, and so on. A mobile "studio" mounted on a golfcart can move around the campus and transmit programs back to the taping center via the two-way capabilities of the system.

C. TWO-WAY CABLE USAGE

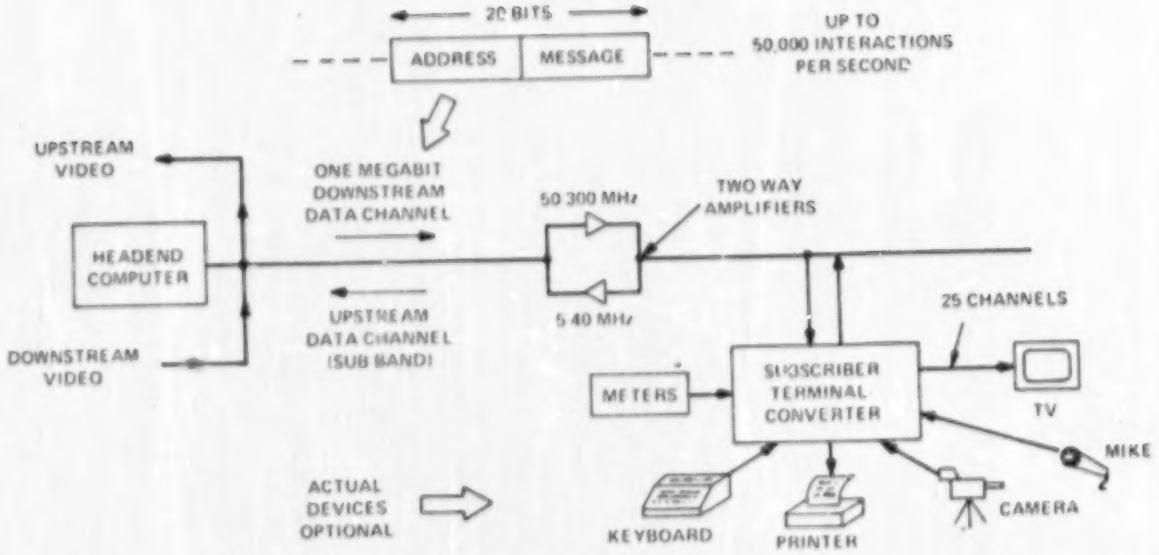
A large number of CATV equipment manufacturers now offer two-way cable amplifiers designed to permit the sub-band range of frequencies (roughly 5-40 MHz) to be transmitted upstream, that is, from the subscribers towards the system headend, on the same cable on which frequencies above 50 MHz are being transmitted downstream. Few of these amplifiers are still operaitonal and in fact only a few tens of miles of cable are involved in various tests and demonstrations, some of which indicate that there are technical problems yet to be solved in bi-directional cable systems. One of the main problems is that there is a different noise problem in the upstream channels than in the downstream channels. In the downstream case, each amplifier receives its input from a single cable leading from a previous amplifier, and input signal-to-noise (S/N) ratio can be closely controlled. In the reverse (upstream) case, however, a number of branches in the tree typically converge on the input of each upstream amplifier, and the noise from these branches is additive across the upstream band. One source of interference affecting the upstream data channels has been identified as broadcast signals from radio stations in the 5- to 50-MHz band leaking into the cable system, particularly at the cable

connectors and improperly terminated house drops. Apparently, a two-way system requires much more careful attention to shielding design and maintenance of shielding integrity than a downstream-only system.[4]

The above simply indicates that upstream transmission in CATV systems is barely under way, and that some unexpected technical problems are being encountered in the initial hardware configurations. These problems appear to be amenable to solution, however, and it may be expected that two-way cable technology will be on a very solid footing with five years, and that there will be a substantial number of installations within that period. In fact, the FCC in its new CATV Report and Order, which became effective March 31, 1972, states that two-way capability "at least on a non-voice basis" will be required in all systems in the top 100 markets by 1977. What sort of two-way capability has not been stated more explicitly by the FCC at this time. If and when the FCC becomes more explicit, the required two-way capabilities will probably be along the lines discussed in the paragraph below.

With perhaps 30 MHz of upstream bandwidth available on a cable, no more than four upstream TV channels can be fitted in and still leave room for upstream data (and perhaps audio) channels. These four TV channels must of course be shared by all subscribers on a given cable, or looking at it another way, no more than four upstream originations can be taking place at the same time per cable. The two-way CATV cable thus provides considerable capability for remote TV origination from any point in the system, but just does not have the channel capacity for private, two-way video conversations in the telephone sense. That capability requires a separate two-way channel per subscriber, which can only be obtained with a hub-type, switched cable network.

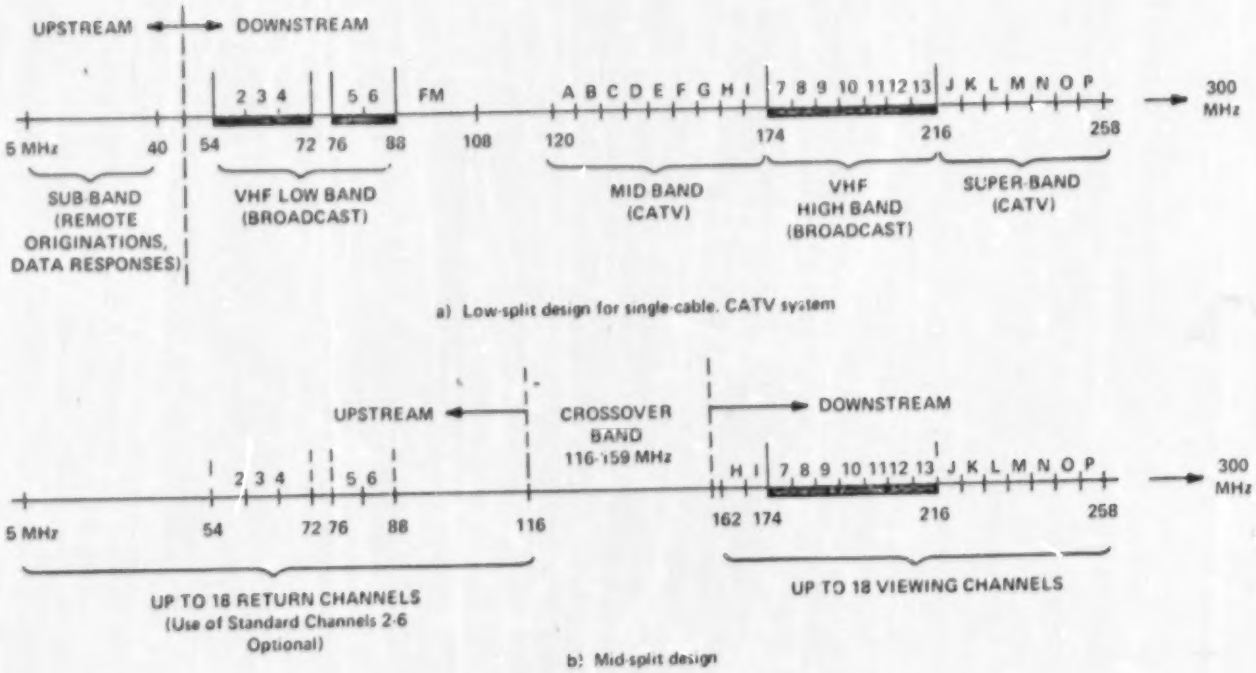
Data transmission capability on a two-way cable is quite extensive, however. Several manufacturers now offer head-end and home terminal equipment which provide time-division-multiplex operation at one megabit per second. As shown in Fig. 5, a single common downstream channel is used (which might be, for example, the unused 4-MHz guard band between VHF Channels 4 and 5), and a single common upstream channel in the sub-band, also of about 4-MHz bandwidth. Each message carries a digital address field, which is recognized by the particular terminal for which it is intended. Messages may contain data for a terminal, control signals for a terminal, or a request for specific input from the terminal (meter readings, etc.), or may be simply a "poll" asking if the terminal has any input and authorizing its transmission in the immediately following time slot. Upstream transmission from a terminal can be identified either by its timing relative to a head-end request, or can also include terminal identification. Assuming that each head-end or terminal transmission consists of 20 bits (12 bits of address, 8 bits of data), and cable propagation time factors are properly handled, all subscribers on a



TYPICAL TWO WAY SYSTEM AS NOW CONFIGURED BY VICOM, INC. (BEING TESTED IN OVERLAND PARK, KANSAS) AND BY HUGHES THETACOM (BEING TESTED IN LOS GATOS, CALIFORNIA).

ANOTHER CONCEPT BEING TESTED BY MITRE CORP. IN RESTON, VA., INVOLVES A "FRAME GRABBER" (TV TAPE OR DISK RECORDER) TO RECEIVE AND DISPLAY ON THE TV SET SINGLE, ADDRESSED, TV FRAMES. DIFFERENT FRAMES CAN BE SENT TO 60 SUBSCRIBERS EACH SECOND.

Fig. 5 Two-Way Concepts



a) Low-split design for single-cable, CATV system

b) Mid-split design

Fig. 6 Comparison of low-split and mid-split cables

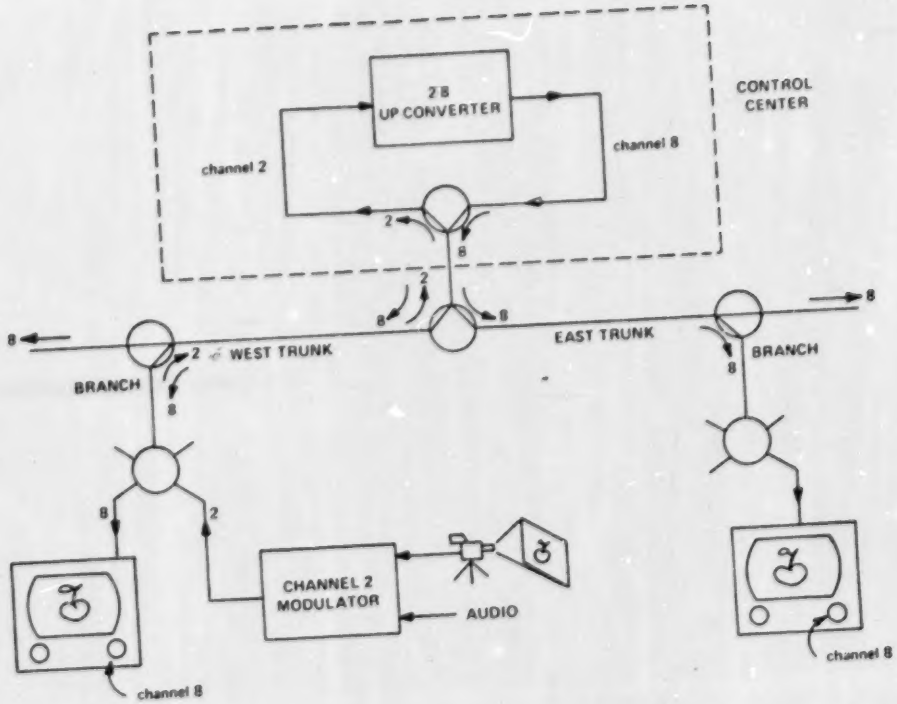
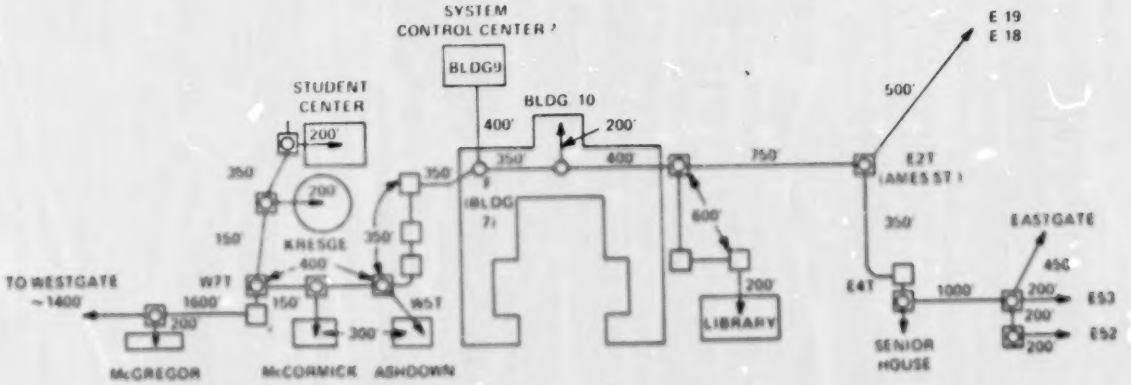


Fig. 7 Control center conversion of remote origination channel to viewing channel



TOTAL CABLE FOOTAGE SHOWN - 11,600'

WEST	EAST	
350	400	(9 ●7)
350	350	
300	200	
300	300	
400	600	
350	200	
200	750	
200	500	
150	350	
1600	1000	
200	450	
1400	600	
5800'	5800'	

○ • SPLITTER

□ = MANHOLE & NUMBER
W7T

Fig. 8 First-cut back-bone cable routing for MIT

4,000-subscriber trunk (or separate 4,000-subscriber data channel on a larger trunk) can be polled five times per second, and each subscriber can thus be provided a simultaneous and continuous two-way data transmission capability of 50 bits per second. If the data channel control is organized so that the available channel capacity can be allocated only among those terminals that are active at a given time, data rates of up to 5,000 bps or more per terminal are feasible, depending on the total data traffic.

An average, simultaneous capability of 50 bps per subscriber will provide sufficient data capacity for almost all of the proposals that have been made for home data services (alarms, meter reading, channel monitoring, home shopping and banking, information access, etc.). As shown in Fig. 5, a wide variety of input/output devices may be part of the subscriber terminal itself, or may be provided as options that may be connected to a "basic" terminal. These include keyboards, soft-copy displays, hard-copy printers, and interfaces for other in-home systems (meters, fire alarms, and burglar alarms). Several of the new terminals coming on the market also provide a few controlled-access audio channels, which permit voice as well as button response in TV teaching situations (one such system has been tested experimentally near Kansas City). They also may be used as party lines to permit "conference call" hookups for any desired group of subscribers, in combination with a video channel allocated to the group for the duration of its conference. A further capability of these systems is channel-access control, which can be used for pay-TV, or for other limited-access programming (medical networks, and others).

Also noted in Fig. 5 is a new concept called "frame grabbing," which requires that each subscriber using this service be equipped with a write/read storage device (magnetic video tape or disk) that can capture one TV frame on a cable channel and then continuously play it back at the proper flicker-free frame rate (30 or 60 per second) for as long as a minute or more for viewing on the TV set. Each such frame is preceded by a digital address code that causes the proper subscriber terminal to record it (this address function can perhaps be combined with the same function on a data terminal if there is one). In the demonstration of this concept by Mitre Corporation,[5] each interlace field (262 lines, 1/60 second) is separately addressed and can be a picture or a text display with up to 800 alpha-numeric characters. For just one "frame grabber" channel, this yields a capacity of 216,000 individually addressed text or picture frames per hour, or 172.8 million characters per hour in text-only mode – a truly enormous information transfer capability. Costs for the necessary subscriber recorder/playback device currently are in the $500-$1,000 range, but this might eventually be reduced to $100 in high production.

A further concept based on the "frame grabber" approach is to time

multiplex a number of "moving" TV pictures on one channel, but with each such picture transmitted at a much slower rate than usual. For example, if each complete TV frame (2 interlace fields) were separately addressed, and a given subscriber received three new frames per second, then 10 different subscribers could each receive a different "stop motion" video signal on the same channel. Just as in the "frame grabber" described above, a subscriber storage device would be needed to capture each new frame and replay it at the proper 30-per-second viewing rate until the next frame was received. The visual effect would be a bit jerky, but probably acceptable for many purposes not satisfied by one-frame-per-call "frame grabber" services, and not warranting a full, dedicated TV channel.

Present Status: Once the technology of two-way data links as described above is firmly established, as appears certain will occur within two or three years at most, the main constraints on installation and use of this technology will be the cost of the home terminal devices ($100 to $1,000, depending on function), and the growth of data services that a subscriber may have access to. This is very much a "chicken or the egg" situation, since subscribers will only be interested in paying additional monthly charges for two-way terminal equipment when there are available services that they would like to use and these same services are unlikely to develop until there are enough subscribers ready (and equipped) to use them to make them worthwhile. It is clear that two-way services will emerge over the next few years, but their rate of growth is extremely hard to predict at this time.

CABLE IN THE UNIVERSITY

A cable system in a university can, of course, be organized just like those that have been described for bringing cable programs to subscriber's homes, and, in fact, some universities have proposed systems in which they become part of neighborhood cable systems carrying primarily entertainment programming, and the universities' needs for special programming are met with extra channels, some of which may be seen throughout the system. At the other extreme, universities may install specialized configurations that are entirely internal in coverage, and are optimized to the purpose at hand. The switched system at Case-Wester-Reserve previously described is an example of this type.

Thinking about a possible broadband cable system within M.I.T. is somewhat similar to that at Case-Western-Reserve, but is currently based on a variation of the two-way, tree-structured cable systems that have been described. The idea is that the entire campus, which extends for two miles in the long direction, be wired with a two-way trunk providing up to 18 upstream and downstream channels at each location. For this, commercially available "mid-split" two-way amplifiers would be used,

with channel assignments as shown in Fig. 6(b). A program originated at any location would be distributed to all other locations by sending it upstream to a control center, where it would be frequency-converted to a downstream viewing channel and sent out over the system. This procedure is shown in Fig. 7. Note that the control center would be in the middle of the system.

Figure 8 shows a preliminary version of an M.I.T. trunk network that would interconnect all major lecture rooms, libraries, and housing units. Excluding distribution wiring within buildings, it is estimated that this trunk system could be installed and three upstream/downstream channel pairs implemented for about $30,000. Regular TV sets would be used for viewing up to six channels; converters would be needed to expand beyond six channels.

REFERENCES

1. There are also microwave relay systems for CATV off-the-air signals, and in 1971 about 600 CATV systems received all or part of their signal inputs via microwave relay rather than their own antennas.

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